

**MOLECULAR BONDING OF MICROELECTRONIC COMPONENTS ON A
POLYMER FILM**

Technical field

The invention relates to the adhesion of microelectronic components on a polymer support.

More specifically, the invention, in one of its aspects, relates to a bonding method so that
5 molecular adhesion is made possible on a surface at least partially coated with a polymer.

In another aspect, the invention relates to a stack of electronic compounds from this method.

Prior art

10 To produce stacked structures, the adhesion of various levels is often ensured by glues, waxes or even photosensitive polymers: the adhesive substances are generally applied on one or both surfaces to be assembled and a drying or hardening step enables the
15 bonding to be ensured.

In the field of electronics, methods for stacking structures by molecular adhesion are also known. However, in this case, it is systematically recommended to remove the hydrocarbons so as to allow
20 for high-quality bonding (see, for example, the work of Q.Y. Tong and U. Gosele "Semiconductor Wafer Bonding, Science and Technology", John Wiley and Sons, Inc., New York (1999), paragraph 5.4.2).

In addition, a planar surface is preferable
25 for providing durable molecular adhesion. Therefore, polymer films are not favourable for such direct

bonding: aside from their significant hydrocarbon content, they have substantial surface porosity.

The development of microelectronics, the miniaturisation of components and the increasing complexity of assemblies has led to the desire to produce three-dimensional structures, in which thick and/or thin chips are stacked on plates of compounds already formed.

In particular, on the initial stack support, electronic components are placed according to conventional methods so as to obtain a host plate. Such methods end up in general by steps making it possible to produce electrical connections, for example, by an application of photosensitive material such as benzocyclobutene (BCB). The photosensitive material present at the surface of the host plate is normally a polymer: the problem is that of being capable of positioning chips or other electronic components at the surface of the polymer in order to produce the three-dimensional structure.

Traditional bonding is not without problems, because any use of glue, polymer, wax, etc. creates an additional thickness that is difficult to manage in such a stack, and has another disadvantage with the possible creation bubbles at the bonding interface. It has also been demonstrated that thin structures bonded to a support via a "thick" adhesive layer had a tendency to become corrugated depending on the nature of the adhesive, the relative thickness, and so on.

Description of the invention

The invention proposes, among other advantages, overcoming the aforementioned disadvantages for the adhesion of microelectronic components on
5 polymer surfaces.

The invention proposes using direct molecular adhesion. To this end, the method according to the invention in one of its aspects makes it possible to overcome the problems caused by the
10 presence of the polymer layer, by coating it with a bonding layer allowing for said molecular adhesion. Surprisingly, it was found that the polymer does not contaminate this bonding layer with hydrocarbons: molecular adhesion is therefore achieved in the
15 presence of a polymer, i.e. hydrocarbons, with quality results, contrary to the prejudices of the prior art. The bonding layer advantageously has, on its surface to be assembled, hydrophilic properties obtained spontaneously or after a specific treatment known to a
20 person skilled in the art. In addition, the bonding layer is preferably chemically inert and compatible with subsequent steps routinely implemented in microelectronics. The materials preferred for producing such a bonding layer are oxides, nitrides or a
25 composite layer, in particular SiO_2 , Si_xN_y , $\text{Si}_x\text{O}_y\text{N}_z$. The bonding layer can also consist of a stack of a plurality of the aforementioned layers.

The bonding layer is advantageously polished so as to obtain a planar adhesion surface;
30 depending on the conditions used, such a polishing is possible without any tearing, whether total or partial,

of the bonding layer from the polymer, which would lead to contamination by hydrocarbons. Thus, it is not necessary to polish the polymer layer to the same degree, a method that is more difficult to control than
5 the polishing of a silicon oxide layer, for example, or other bonding layer materials.

It is also possible to prepare the bonding layer surface according to methods enabling the adhesion-energies to be increased. Also to this end,
10 the method according to the invention advantageously proposes preparing the contact surface of the compound that will be placed on the bonding layer.

It may be preferable to prepare the polymer prior to the deposition of the bonding layer, for
15 example by performing a cross-linking operation. It is also possible to consider consolidating the assembly after molecular adhesion by a heat treatment.

In another aspect, the invention relates to a three-dimensional electronic component structure
20 including a stack, of which some adhesions between successive layers, and more generally between successive levels, are direct, with the deposition of at least one interface layer, of silicon oxide for example.

25 **Brief description of the drawings**

The figures of the appended drawings will make it possible to better understand the invention, but are given only by way of indication and are in no way limiting.

Figures 1a to 1d diagrammatically show the various steps of a method according to a preferred embodiment of the invention.

Figure 2 shows, in an exploded view, an embodiment of the invention concerning a three-dimensional stack.

Detailed description of particular embodiments

The invention has a particular application in stacks of electronic, optical, or optoelectronic structures, for example, for producing three-dimensional arrays consisting of plates including components, for example electronic or optical components. These plates can themselves be made up of supports, to which components, possibly different, have been secured and of which the connections have been created. The simplest example, however, relates to a single electronic component, or chip, to be "glued" to the surface of a conventional electronic compound, or host plate.

Such a plate 1, shown in figure 1a, consists of a support 2, on which various electronic components 3 have been produced according to known techniques. The support 2 is partially coated with a polymer 4, for example, used in one of the steps leading to the electrical connection of the components 3 of the host plate 1, and of which the thickness routinely ranges from 1 to 20 μm , preferably remaining lower than 10 μm ; the surface of the host plate 1 can contain, in particular, a BCB film, but a glue or a wax are other possibilities.

For the method according to the invention, it is preferable to prepare the surface polymer 4, in particular to dry it, so as to stabilise it. In particular, it is desirable to perform an additional cross-linking operation on the polymer, for example, by a heat treatment with heating between 150 and 400 °C, in one of the final steps of forming the host plate 1. For example, for a BCB film, typically on the order of 6 µm, a heat treatment of 2 h at 250 °C or 300 °C, or even 30 min at 350 °C, can be envisaged.

The polymer 4 is then coated with a bonding layer 5, if possible chemically inert and capable of withstanding the usual microelectronics treatments, preferably in the form of a deposited film: figure 1b. The bonding layer preferably consists of silicon oxide, or it is possible to choose a nitride or a silicon oxynitride; however, it can be made of any material capable of forming a layer that is advantageously hydrophilic (inherently or by a suitable treatment) so as to ensure molecular adhesion. The bonding layer 5 can be uniform, but it can also consist of a superimposition of uniform layers as described above, for example, a SiO₂ layer coating a Si_xO_yN_z layer.

If the electronic compound 3 has polymer-free zones 4 on its surface, only the polymer can be coated, but it is easier to coat the entire surface of the plate 1. The silicon oxide 5 or other material can be deposited by known techniques, for example, by a "low-stress" method, at 220 °C, for example, or a plasma-enhanced chemical vapour deposition method, at a temperature of 300 °C, for example. It is of course

desirable for the deposition temperature to be compatible with the aforementioned cross-linking operation. The thickness of the bonding layer 5 produced can be between 50 and 300 nm, preferably on the order of 150 nm; surprisingly, these thicknesses are sufficient for providing a barrier to the hydrocarbons present in the polymer 4. The thickness is chosen in particular so as to be relatively thin to prevent an excessive stiffening effect, but thick enough to allow for subsequent treatments, in particular, for example, the polishing so as to render the surface planar.

Indeed, the surface of the bonding layer 5 is then preferably prepared for bonding. In particular, a polishing step is desirable, so as to obtain a sufficient levelling of the surface and a sufficient microroughness to allow for direct subsequent bonding. The polishing can be performed by a chemical mechanical method, for example, chemical mechanical polishing (CMP) or water polishing on a specific tissue, also known as "slurry cleaning". The polishing also makes it possible to reduce the thickness of the oxide layer to 30 to 150 nm; it is possible, for example, to remove 80 nm of 150 nm. This step, surprisingly, does not cause any tearing, whether partial or total, of the bonding layer 5 that, aside from roughnesses, would cause contamination with hydrocarbons. Simultaneously to the polishing, or as a replacement, the surface can be activated for subsequent molecular adhesion, for example with a mixture of oxygenated water and ammoniac, substantially diluted with water. It is also possible

to treat the silicon oxide film with one of the following techniques, alone or in combination: ultraviolet or ozone treatment or any other surface preparation allowing for high adhesion energies such as
5 plasma treatment (under oxygen, argon, nitrogen, hydrogen, etc.).

Similarly, to improve the adhesion, the active or inactive surface of the chip 6 (see figure 1c) which will come into contact with the silicon oxide
10 layer can be cleaned and/or polished and/or subjected to a specific treatment similar to the preparations mentioned for the bonding layer 5. It is also possible to coat it with a polished silicon oxide layer 7 or any other layer similar to the one coating the polymer. It
15 is also possible to perform, using standard techniques known to a person skilled in the art, a treatment enabling the roughness of at least one of the oxide films 5, 7 to be increased in a controlled manner, so as, for example, to allow for a subsequent debonding at
20 the level of this rough surface. Of course, the resulting roughness will be compatible with the molecular bonding (see H. Moriceau et al., "The bonding energy control: an original way to debondable substrates", Conference of International Electro-
25 Chemical Society, Paris, June 2003). This alternative is particularly advantageous in the case of three-dimensional assemblies in which one of the stacked levels is to be removed, for example, after this level has been tested.

30 The chip 6 is then preferably bonded directly to the surface of the electronic compound 1

coated with SiO_2 : figure 1d. The direct molecular adhesion bonding can be performed on the active surface of the chip, as well as on its inactive surface, depending on the requirements. For more specific
5 information on molecular adhesion, reference can be made to the work of Q.Y. Tong and U. Gosele "Semiconductor Wafer Bonding, Science and Technology", John Wiley and Sons, Inc., New York (1999).

To reinforce the direct bonding, a
10 complementary heat treatment can be performed, for example, a consolidation at temperatures above 100°C .

The method according to the invention therefore allows for bonding between a chip 6 and an electronic compound 1, of which the surface contains a
15 polymer 4, without requiring an additional adhesive substance to be managed; in particular, there is no bead of excess glue on the chip and problems concerning the choice of parameters (nature and form of the glue, spreading of drops, etc.) for preventing the creation
20 of bubbles during bonding are naturally resolved.

In addition, the final bonded structure has a lower and better-controlled thickness than with the use of an adhesive, which adds a thickness that is difficult to predict. Admittedly, an oxide layer 5 is
25 added, but its thickness remains low (in particular much lower than $1\text{ }\mu\text{m}$) and in any case well controlled.

The low thickness due to the actual bonding (i.e. the thickness of the SiO_2 layer resulting from the method, between 30 and 300 nm, for example, and
30 preferably on the order of 50 nm) also enables a step change, located between the chip and the host plate,

facilitated for contact on the edges of the chip: it is easy to establish contact between the unbonded surface of the chip and the initial support in this case, where only several micrometers at most (in fact, the thickness of the chip 6) separate them. It may be desirable, in order to further facilitate the step change, to use a bevel 8 on the edges of the chip 6. The bevel 8 can correspond to a profile obtained by etching (for example, by anisotropic chemical etching, sensitive to the crystalline orientation of the bevel planes) or by cleavage (for example, in a preferred crystalline direction: in the case of $\langle 100 \rangle$ silicon plates used to produce chips, the cleavage surfaces will be, for example, the $\langle 111 \rangle$ planes corresponding to an angle of 54° 7).

In addition, the preparation, and in particular the levelling, of the surface of the host plate prior to bonding, are easier than when an inserted adhesive substance is used: it is possible to leave the surface of the polymer as it is after deposition, in particular if the polymer film has a low thickness, or to perform only one rough polishing operation, with the bonding surface being defined by that of the bonding layer, of which the polishing can be managed and controlled better than for a polymer.

The bonding of chips by molecular adhesion is also more easily controlled, for example in the positioning of the chips, than bonding with an adhesive substance, and all the more so if the chips are thin. Highly thinned chips, or even films, can also be bonded to the BCB coated with an oxide film by transfer: an

intermediate support for transferring these chips can be used in the method of the invention. The thinned chip is thus temporarily secured to a support, the surface left free is prepared specifically as described
5 above so as to allow for direct bonding with the final support coated with the polymer and the bonding film. The intermediate support is then detached after the adhesion according to known techniques (see, for example, FR 2 796 491). A significant reduction in the
10 tendency of the transferred elements (chips or films) to become corrugated, or even the removal of this phenomenon, is noted by comparison with the conventional bonding using an adhesive substance.

Another important advantage of the method
15 according to the invention is that it enables the thinning of the chips bonded to the BCB and the oxide film, without any, or almost any, corrugation. If the active surface of the chip was placed in contact for adhesion with the SiO_2 layer, most of the back surface
20 of the chip can indeed be removed, by grinding, polishing, chemical attack, debonding, a pedestal removal technique known as "lift off", and so on, so as to leave only a thin film containing the active surface on the bonding interface side.

25 The description above relates to a chip on an electronic compound plate, but it is clear that a generalisation to any form of electronic compound can be directly derived; the term electronic compound refers to any compound obtained by means conventionally
30 used in microelectronics and capable of having microelectronic, optoelectronic, optical, hyper-

frequency applications and so on. With a similar method, the following can in particular be bonded to an "initial support": a monolithic plate, a stacked structure, a developed structure, a film, on the active surface or not, with or without "via holes". Similarly, the "initial support" for bonding must not be limited to the previous example of "electronic compound host plate", but can include the same variety of elements as described above for the bonded element.

10 The method can thus be repeated a plurality of times, so as to produce a multi-level structure. As shown in figure 2, this structure 10 can, for example, consist of a stack of compounds 1, 1', 1'', for example having similar shapes and or external sizes but of possibly different types, each capable of being secured to the preceding by molecular adhesion, on an SiO₂ coating layer 5 if the adhesion surface contains a polymer 4. One of the preferred three-dimensional structures 10 thus produced is designed so that each compound 1, 1', coated with a polymer 4 is totally coated with an SiO₂ layer 5 before being placed on this interface layer 5, which is a molecular adhesion layer, of the next component 1', 1''.